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(54) **Magnetic head core and method for producing the same.**

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Description

The present invention relates generally to a core of a magnetic head and a method of producing such a magnetic head core, and more particularly to a magnetic head core formed of ferrite with a coil-winding aperture and a magnetic gap.

In the art of magnetic heads for various types of recording media, a core made of ferrite has been known, which generally consists of a pair of ferrite core elements joined together to form a structure of ring-shaped or toric cross section having a centrally located large aperture or void which facilitates winding of coils around the core elements. More specifically stated referring to Fig. 1 which shows a common type of magnetic head core, a pair of generally C-shaped ferrite core halves 2, 4 are butted together to form the core with a central aperture 6 which serves as a space for winding coils 8 around the core halves 2, 4. In this manner, an annular or toric magnetic circuit is constituted by the two C-shaped ferrite core halves 2, 4. In the meantime, the toric magnetic core structure is formed with a magnetic gap 10 at one end portion of the core. The gap 10 is formed to extend across the toric magnetic circuit and has a suitable width α which is the distance between the opposed end surfaces of the core halves 2, 4. As is well known in the art, a magnetic tape 12, magnetic disk or other magnetic recording medium is slidably moved on outer contact surfaces of the core halves 2, 4 in the proximity of the magnetic gap 10 defined by these halves 2, 4, whereby magnetic writing (recording) and reading (reproducing) processes are effected.

As indicated above, the ends of the core halves 2, 4 at one end of the core have the opposed surfaces which are spaced from each other by a distance equal to the width α of the magnetic gap, while the other ends of the core halves 2, 4 are bonded together with suitable bonding glass so as to maintain a generally toric cross sectional shape of the magnetic core as a whole. In this known ferrite core formed of the two core elements 2, 4 bonded together with glass, however, it is inevitable that a very small gap 14, so called a rear or back gap, is formed between the bonded abutting surfaces of the core elements 2, 4. The existence of this rear gap 14, which is located opposite to the magnetic gap 10 at the front of the core, necessarily increases the magnetic resistance of the magnetic circuit, and consequently has an adverse effect on the sensitivity, and signal to noise ratio (S/N ratio) of a magnetic head using the core, which sensitivity and S/N ratio are important characteristics of the magnetic head. In other words, it is required to completely eliminate the rear gap 14, i.e., to reduce the width of the gap to zero in order to maximize the sensitivity of the magnetic head, and accordingly improve the S/N ratio. However, this requirement has not been satisfied by any conventional ferrite core formed of plural core members or elements as described above.

When these core elements 2, 4 of the core are both made of ferrite polycrystal, there have been experienced the problems that the surfaces in the vicinity of the magnetic gap are subject to uneven wear due to their relative sliding contact with a magnetic recording medium such as the magnetic tape 12, and that grains of the polycrystalline ferrite drop out from opposed surfaces defining the magnetic gap, during the process of forming such gap-defining surfaces, thus causing the gap-defining surfaces to be rough having small indentations and projections. In view of these problems, it is conceivable to form the core elements 2, 4 of the single crystal of ferrite. In this case, there arises another problem in addition to the presence of the aforementioned rear gap at the abutting portions of the elements. That is, extremely expensive single crystal ferrite should be used for plural core elements, and the material cost of the core is accordingly increased. When relatively large ferrite core elements are required to fabricate a relatively large core, correspondingly large single crystal ferrite blocks are required, which pushes up the cost of manufacture of the core and requires a higher level of technology.

Methods of making magnetic head cores consisting at least partly of single crystal ferrite and involving direct bonding to a plurality of ferrite core elements by solid-solid reaction are fully described in our copending application published as EP—A—148 014.

For earlier disclosed methods of forming ferrite single crystals, reference can be made to our earlier applications EP—A—39593 and EP—A—53481.

It is accordingly an object of the present invention to provide a magnetic head core which has substantially no rear gap and improved wear resistance, and a method of producing such a core.

Another object of the invention is the provision of such a magnetic head core of generally ring-shaped integral structure which is formed of plural core elements of ferrite with a narrow magnetic gap, and which provides for improved sensitivity and signal-to-noise ratio of the magnetic head, and an easy and economical method of producing the same.

According to the present invention, there is provided a magnetic head core as set out in claim 1.

According to another aspect of the invention, there is provided a method of producing a magnetic head core as set out in claim 2.

In the ferrite magnetic head core of the invention constructed as described above, the generally annular magnetic circuit is formed of a single crystal of ferrite, and therefore there exists no hetero phase in the magnetic circuit. In particular, the core consists of plural core elements which are directly bonded together through solid-solid reaction or solid-phase reaction, and is substantially free of such rear or back gap that is inevitably present in the known core wherein the core elements are bonded together with a bonding glass. Accordingly, the core of the invention suffers virtually no magnetic resistance due to such a rear gap, and the use of the instant core effectively improves the sensitivity and signal-to-noise ratio of a magnetic head.

Further, it will be obvious that the use of two or more ferrite core elements according to the invention to constitute an integral core assembly permits easy formation of the magnetic gap with a desired width between the opposed core elements. This means that the magnetic gap is easily formed with a relatively small width, ranging from 0.4 microns to 3 microns approximately. The core with such a narrow magnetic gap is suitably usable for magnetic heads for VTR and computer applications.

As indicated above, an at least partially monocrystalline block of ferrite may be advantageously used as one of the plural core elements. This partially monocrystalline block includes a monocrystalline portion consisting of a single crystal of ferrite. As a result of growth of the ferrite single crystal of this partially monocrystalline block, at least one of the opposed portions defining the magnetic gap is monocrystallized. In other words, the other core elements used may be wholly polycrystalline blocks of ferrite. Therefore, the number of expensive blocks of ferrite single crystal, or the amount of use of such costly monocrystalline ferrite material, is minimized, and consequently the cost of manufacture of the core is effectively reduced. In addition, the use of plural ferrite core elements one of which is at least partially monocrystalline, eliminates the need for a large block of ferrite single crystal to manufacture a relatively large ferrite core, and obviates the difficulty in producing such a large-sized monocrystalline ferrite block.

In accordance with the method of the invention, the magnetic head core constructed also according to the invention and having the foregoing features is easily and economically manufactured. According to an advantageous embodiment of the instant method, a pair of elongate blocks of ferrite are used as the polycrystalline and at least partially monocrystalline blocks. These elongate ferrite blocks are butted and bonded together through solid-solid reaction or solid-phase reaction into an elongate assembly having a cross sectional shape corresponding to the generally annular magnetic circuit. The elongate assembly of the bonded two elongate blocks are cut in parallel planes perpendicular to the length of the assembly. In this instance, the magnetic head core of the invention is obtained in plural number from a pair of elongate blocks of ferrite. Thus, the manufacturing economy is considerably boosted.

According to another embodiment of the method of the invention, the mutually abutting surfaces at which the two blocks are bonded together are disposed at the other end portion of the assembly remote from the magnetic gap at said one end of the assembly, and the growth of the ferrite single crystal of the monocrystalline portion of the at least partially monocrystalline block proceeds across the mutually abutting surfaces of the two blocks which have been bonded together by solid-solid reaction at the other end portion of the assembly.

According to an alternative embodiment of the instant method, the assembly of the two blocks has a first pair of mutually abutting surfaces on said opposed portions of the two blocks at said one end portion of the assembly, and a second pair of mutually abutting surfaces at the other end portion thereof, the first pair of mutually abutting surfaces being disposed outside said magnetic gap. The growth of the ferrite single crystal of the monocrystalline portion of the at least partially monocrystalline block proceeds across the first and second pairs of mutually abutting surfaces of the two blocks which have been bonded together by solid-solid reaction at said one and other end portions of the assembly. In this case, at least one of the opposed portions defining the magnetic gap is monocrystallized through the growth of the ferrite single crystal across said first pair of mutually abutting surfaces adjacent to the magnetic gap. This indicates that it is not alway necessary to form the ferrite core of a single crystal. According to the instant method of the invention, at least the opposed portions defining the magnetic gap and their vicinities are easily and suitably monocrystallized through the aforementioned growth of the ferrite single crystal.

Thescore elements used to form a ferrite core according to the invention are made of ferrite materials such as Mn-Zn ferrite and Ni-Zn ferrite, which are selected depending upon the specific applications of the ferrite core. As a rule, the plural core elements used in the invention are made of the same ferrite materials. Further, it is important to use, as one of the core elements, a monocrystalline ferrite element at least a portion of which is made of ferrite single crystal. The mono-crystalline portion of the ferrite element grows toward a polycrystalline ferrite portion or portions. Although this at least partially monocrystalline ferrite element may be wholly made of a single crystal of ferrite, it is economically advantageous to use a composite of monocrystalline and polycrysatalline ferrite structures, at least a portion of which is made of a single crystal.

While the ferrite core element or elements other than the at least partially monocrystalline ferrite element have a polycrystalline ferrite structure originally made of ferrite polycrystal, it is required that the polycrystalline ferrite elements undergo discontinuous grain growth. Stated more specifically, the polycrystalline ferrite element used according to the invention should be ferrite polycrystal wherein when the firing temperature is elevated beyond a critical point, some of the grains suddenly start to grow at a rate extremely higher than that of the surrounding microcrystal grains, and integrate or unite these surrounding grains, thereby growing into a giant single crystal (single macrocrystal). This property of polycrystalline ferrite is disclosed in greater detail in Japanese Patent Applications, Serial Nos. 54-67893, 55-59167 and 55-166644 which were filed in the name of the assignee of the present application and laid open Dec. 17, 1980, Dec. 1, 1981 and June 9, 1982 under Publication Nos. 55-162496, 56-155100 and 57-92599, respectively. Such polycrystalline fèrrite materials as disclosed in these Applications are usable in this invention.

According to the invention, each of the core elements of ferrite polycrystal exhibiting the above-indicated discontinuous grain growth is generally prepared by press-forming and sintering a mixture mass of ferrite powders comprising an iron oxide which is one of major components of the powder mass, and which contains an iron oxide of spinel structure and/or an iron oxide having spinel structure hysteresis in a total amount of not less than 60% by weight, calculated as Fe_2O_3. The ferrite polycrystal is contacted with a ferrite single crystal of the adjacent monocrystalline core element, and the single crystal grows in the direction toward the polycrystal, whereby the microcrystal grains in the polycrystal are integrated with the single crystal with a result of growing the single crystal.

Embodiments of the present invention will now be described by way of example with reference to the accompanying drawings in which:

Fig. 1 is an illustration of a magnetic head arrangement known in the prior art;

Fig. 2 is a view illustrating the process of assemblying the embodiment of a magnetic head core of the invention, and the construction thereof;

Fig. 3 is a view corresponding to Fig. 2, showing another embodiment of the invention;

Fig. 4 shows the process in which a ferrite polycrystal with a thermally etched surface is changed into a ferrite single crystal with recovery of the etched surface into a flattened smooth surface;

Fig. 5 is a cross sectional view showing a core assembly of ferrite core elements of the invention accommodated in an alumina heating box; and

Figs. 6 and 7 show the steps of producing a magnetic head core of the invention according to different embodiments of a method of the invention.

Referring to Figs. 2—7 of the accompanying drawing, several embodiments of a magnetic head core and a method of the invention will be described in detail.

There are first shown in Fig. 2 a pair of core elements 16, 18 of ferrite which are butted together at abutting surfaces 17, as shown on the left hand side of Fig. 2, so that a generally annular magnetic circuit is formed. The element 16 is a partially monocrystalline core element having a monocrystalline portion 15 consisting of a ferrite single crystal, and the other element 18 is a wholly polycrystalline core element. The mutually abutting surfaces or portions 17 of the two ferrite core elements 16, 18 are bonded together through solid-solid reaction or solid-phase reaction, and a generally ring-shaped integral assembly 20 is obtained as a ferrite core of the invention, as depicted on the right hand side of the figure, wherein substantially no bonding boundary interface (17) (rear gap) is present between the bonded core elements 16, 18 at one end portion of the ferrite core 20. The monocrystalline or single crystal portion 15 of the partially monocrystalline element 16 is caused to grow toward a polycrystalline portion 19, and the growth of the single crystal further proceeds across the bonding boundary interface 17 toward the wholly polycrystalline element 18 as indicated by arrows in the figure, whereby the entirety of the integral magnetic circuit assembly, i.e., ferrite core 20 is monocrystallized. At the other end portion of the core 20, opposite to the bonded portions of the elements 16, 18, there is formed a magnetic gap 22 which is defined by opposed end surfaces of the partially monocrystalline and wholly polycrystalline core elements 16, 18. The magnetic gap 22 is formed transversely across the annulus of the magnetic circuit of the core 20, and has a predetermined width α which is the distance between the opposed end surfaces of the core elements 16, 18. The core element 18 has a recess or groove and cooperates with the core element 16 to form a centrally located aperture 24, which facilitate a process of winding coils around the core elements 16, 18. It will be obvious that as result of the aforementioned monocrystallization due to the single crystal grain growth, the opposed end portions of the elements 16, 18 defining the magnetic gap 22 and providing contact surfaces for a magnetic recording medium consist of a single crystal of ferrite.

The magnetic head core of the invention is suitably and advantageously prepared through solid-solid reaction and monocrystallization, as illustrated in Fig. 3.

More particularly, the partially monocrystalline core element 16 and the wholly polycrystalline core element 18 are butted together at their opposite ends such that the magnetic gap 22 is defined by the opposed end surfaces which are located inside the abutting portions at one end of the butted assembly. In this condition, the core elements 16, 18 are heated, and the abutting portions are bonded together. In the meantime, the monocrystalline or single crystal portion 15 partially defining the magnetic gap 15 and serving as the medium-contacting portion is caused to grow toward the polycrystalline portions of the elements 16, 18 as indicated by arrows on the left-hand side of Fig. 3. Described in more detail, the monocrystalline portion 15 of the partially monocrystalline element 16 is directly contacted with the medium-contacting end portion of the wholly polycrystalline element 18, and thereby bonded thereto. With this direct abutting contact, the monocrystalline portion 15 grows across the abutting interface 17 outside the magnetic gap 22, and the single crystal growth progresses in the polycrystalline element 18. Thus, ths obtained ferrite core 20 is of single crystal structure at least at its medium-contacting end portion in the vicinity of the magnetic gap 22.

In the middle and right-hand side views of Fig. 3, the crystal structure of the ferrite core 20 upon rapid heating thereof is illustrated. As described later, the ferrite core 20 is not entirely monocrystallized, but the middle and rear portions of the core 20 are polycrystalline structures with comparatively large grain size due to discontinuous grain growth.

The ferrite core 20 thus obtained through solid-solid or solid-phase reaction bonding and monocrystallization is then subjected to a process of filling the magnetic gap 22 with protective glass 21. Subsequently, the core 20 is cut at the end of the magnetic gap 22 to remove the front bonded portion outside the gap 22, so that the gap 22 is exposed to the outside and the medium-contacting surface 23 is formed adjacent to the gap 22, for sliding contact with a magnetic tape or other magnetic recording medium. In this manner, the ferrite core 20 of the invention is provided with the generally annular magnetic circuit having the magnetic gap of a suitable size.

The medium-contacting surface 23 of the core 20 is given a desired curvature as shown, or formed generally flat. Subsequently, coils are wound around the core 20, by utilizing a space of the coil-winding aperture 24 provided in the annulus of the magnetic circuit. Thus, the intended magnetic head core is finally obtained.

In butting the two core elements 16, 18 together, it is desired to apply a ferrite-dissolving acid such as hydrochloric acid, nitric acid or sulfuric acid to the mutually abutting surfaces. Such an acid is applied for the purpose of forming salts of the ferrite component such as iron nitrate, manganese nitrate and zinc nitrate, which serves to secure the core elements 16, 18 relative to each other, and which is decomposed into oxides, upon subsequent heat application. These oxides function to accelerate the solid-solid reaction or solid-phase reaction of the core elements 16, 18, which results in the bonding of the two elements. In place of the above indicated acids, it is possible to use a solution of inorganic salt including a ferrite component, which solution produces almost the same effects and results as the acids, upon abutting bonding of the two core elements 26, 40.

According to the method of the invention, the integral solid-solid reaction bonding of the partially monocrystalline core element 16 and the wholly polycrystalline core element 18, and the monocrystallization of the ferrite polycrystal of the element 18, will take place concurrently and continuously. Since the sintering of the core elements 16, 18 through solid-solid reaction occurs at a temperature of about 1100°C, it is required that the mutually abutting portions of the elements be heated to 1100°C or higher to obtain direct bonding of the abutting portions. It is further noted that the monocrystallization or single crystal grain growth incident to the solid-solid reaction bonding will start at a temperature below a point at which the discontinuous grain growth starts in the ferrite polycrystal (1380°C, in the following Example), more specifically, start at a temperature 50°C lower than that point (1330°C in the Example). Therefore, the monocrystallization of the entire ferrite polycrystal is possible by slowly elevating the heating temperature (at a rate of 20°C/hr, for example) from about 1350°C.

If it is sufficient to monocrystallize only the medium-contacting portion and its vicinities of the ferrite core 20 adjacent the surface 23 as shown in Fig. 3, the heating may be conducted at a relatively higher rate, e.g., at 300°C/hr. In this instance, the ferrite polycrystal of the elements 16 and 18 undergoes a discontinuous grain growth, and monocrystallized solely at its portion near the monocrystalline portion 15 of the element 16, due to the single crystal growth of the latter. However, the polycrystalline structures of the elements comparatively distant from the monocrystalline portion 15 are not monocrystallized, but their original microcrystal grains on the order of some tens of microns are grown to relatively large macrocrystal grains (polycrystal) of several millimeters. Even though such macrocrystal grains exist in the ferrite core 20, the object of the present invention is sufficiently attained, as long as the opposed end portions defining the magnetic gap 22 are ferrrite single crystal.

Even after the wholly polycrystalline core element 18 has been monocrystallized in part or in toto through the single crystal growth, that is, even after termination of the single crystal growth in the core 20, it is desired to keep the core at the elevated temperature so that a surface 26 of the element 18 partially defining the magnetic gap 18 is effectively flattened or smoothed. Described more specifically referring to Fig. 4, the gap-defining surface 26 of the wholly crystalline element 18 is thermally etched prior to the monocrystallization, and indented at the grain boundaries. Consequently, the surface 26 immediately after the monocrystallization is rough or uneven. The recovery of the gap-defining surface 26 from this uneven state is not achieved immediately after completion of the monocrystallization. To remedy this defect, the core 20 is kept at an elevated temperature, preferably higher than the monocrystallization temperature, for a suitable time span after the monocrystallization, during which the thermally etched rough surface 26 is smoothed.

Generally, the heating operation of the assembly of the ferrite core elements 16, 18 for the solid-solid reaction and monocrystallization is conducted in a heating furnace. The atmosphere in the heating furnace is important to maintain the characteristics of the ferrite, and should be carefully selected, since the characteristics of the ferrite are considerably deteriorated through oxidation or reduction in the heating process. Consequently, it is important to use the atmosphere whose oxygen partial pressure is equal to that of the ferrite, i.e., equilibrated oxygen partial pressure. Whereas, the control of the oxygen partial pressure of the heating atmosphere is very difficult to achieve. The easiest method which is considered available is to heat the butted core elements 16, 18 in a heating box made of ceramics such as alumina.

For adjusting the atmosphere within such a ceramic heating box in which the ferrite core elements 16, 18 are introduced, it is generally desired to introduce therein a dummy member in the form of powder or sheet of the same ferrite as the core elements. During the heating of the ferrite core elements 16, 18, the dummy ferrite member discharges and absorbs oxygen, thereby functioning to adjust the oxygen concentration of the atmosphere in the ceramic heating box.

An example of such heating arrangement is illustrated in Fig. 5, wherein the assembly of the core elements 16, 18 is accommodated in an alumina box 27 such that the assembly is enclosed by ferrite dummy plates 28 also disposed in the alumina box 27. This box 28 loaded with the core elements 16, 18 and dummy plates 28 is introduced in a heating furnace.

While the steps of production according to the invention have been described referring to specific examples of Figs. 2—5 wherein a single ferrite core is produced from the core elements 16, 18, it is appreciated, from the economic and commercial point of view, to use a pair of elongate blocks of ferrite as shown in Figs. 6 and 7, for producing plural ferrite cores from a bonded assembly of these two elongate ferrite blocks by cutting the completed assembly into the individual cores of suitable dimensions.

Stated more specifically with reference to Fig. 6, the pair of elongate rectangular blocks of ferrite 30, 32 are used as the starting materials. The block 30 is wholly polycrystalline while the block 32 is a ferrite single crystal. The wholly polycrystalline block 30 is subjected to a groove forming process for forming a groove 34 which partially defines an aperture for facilitating a subsequent process of winding coils. In the meantime, the single crystal or monocrystalline block 32 is coated, except at a gap-defining surface 36, with a chemically resistant film 38, and then subjected to a chemical etching process to remove stock from the gap-defining surface 36 to a depth β corresponding to a width of a magnetic gap.

Usually, the groove 34 is formed in the wholly crystalline block 30 by cutting with a diamond cutter. However, it is alternatively possible to press-mold the block 30 with such a groove.

The stock removal from the monocrystalline block 32 to the depth β to provide the gap-defining surface 36 is suitably accomplished by chemical etching, usually by using inorganic acids as an etching agent, such as hydrochloric acid, nitric acid, sulfuric acid, phosphoric acid, or mixtures or aqueous solutions thereof. However, the use of phosphoric acid is most preferred for improved straightness of the finished surface. The chemical etching process for the stock removal may be replaced by a suitable grinding process. The use of an ordinary blade such as a diamond blade does not generally permit sufficiently high accuracy of removing the stock exactly by a predetermined depth β, e.g., a few or several microns. According to the method of the invention, therefore, the grinding process is carried out by a rotary blade whose peripheral portion is made of a soft material such as rubber and polyurethane and contains abrasives of diamond. The blade containing the diamond abrasives is applied to the gap-defining surface 36 with a slight pressure exerted, such that the stock is removed at a low rate. Thus, the intended gap-defining surface 36 is obtained.

When the stock removing process is achieved by chemical etching, it is desired to etch the single crystal surface of the monocrystalline block 30, rather than the polycrystalline block 32, because the polycrystalline structure is not etched consistently due to difference in direction of crystal grains and the etched surface tends to be rough. Further, even when the single crystal or monocrystalline block 32 is subjected to chemical etching, it is preferred to select the type of crystal face. That is, the crystal face (110) tends to suffer from the generation of oblique line scratches as a result of etching. To avoid this defect, it is recommended to select symmetrical crystal faces, that is, the crystal face of the type (111) or (100). For the reasons stated above, it is particularly preferred that the single crystal block 32 has the crystal face (111) or (100).

The polycrystalline block 30 with the groove 34, and the single crystal block 32 with the gap-defining surface 36 are superposed on each other in mutually abutting relation, and heated for sintering and integral bonding through solid-solid reaction at the abutting portions, whereby an elongate bonded assembly or core block 40 is prepared, with a magnetic gap 42 formed between the two blocks 30, 32. In the meantime, the ferrite polycrystal of the polycrystalline block 30 is entirely monocrystallized due to single crystal growth of the ferrite single crystal of the block 32 which is held in abutting contact with the ferrite polycrystal, in the same manner as described in association with the example of Fig. 2. As a result, even the opposed end portions defining the magnetic gap 42 and serving as medium-contacting portions are monocrystallized.

Subsequently, the magnetic gap 42 formed in the elongate core block 40 is filled with a mass of glass 44, and then the core block 40 is cut in parallel planes perpendicular to its length at suitable intervals, whereby a plurality of ferrite cores 46 of the same size are obtained one after another. Prior to or following this cutting process, the assembly 42 is subjected to a suitable process for forming a contact surface 48 with which a recording medium is brought into sliding contact.

The filling of the magnetic gap 42 with the glass 44 is effected by melting the glass 44 and pouring the melt into the gap 42. Generally, a suitable solid glass in the form of a rod of the like is located adjacent to the magnetic gap 42, and heated at 600—900°C, so that the molten glass flows to fill the gap 42. As in the preceding heating process for solid-solid reaction and monocrystallization, the filling of the gap 42 with the glass 44 should be conducted in the atmosphere of equilibrated oxygen partial pressure. Since the temperature for melting the solid glass is lower than the solid-solid reaction and monocrystallization temperatures, this glass filling process is generally effected in a nitrogen (N_2) gas.

Another embodiment is shown in Fig. 7, which is different from the preceding embodiment of Fig. 6 that is the modification of the embodiment of Fig. 2. More particularly, the instant embodiment of Fig. 7 is a modification of Fig. 3 for increased economy of production on the commercial basis. The groove 34 is formed in the ferrite polycrystal of the block 30, while the surface of the monocrystalline block 32 is coated with chemically resistant films 38 which are not applied to the gap-defining surface 36. The thus coated surface of the monocrystalline block 32 is chemically etched to remove stock from the gap-defining surface 36 to form a gap-defining groove 50 with a depth β which gives a predetermined width α of the magnetic gap 42.

In the next step, the thus processed two elongate core blocks 30, 32 are butted together as shown, and heated for solid-solid reaction at the abutting portions, as previously discussed. Thus, an integrally bonded elongate assembly (core block) 40 is obtained. Meantime, the ferrite single crystal of the block 32 grows across the butted and bonded interfaces at the transversely opposite ends of the assembly 40, and the ferrite polycrystal of the block 30 is comparatively effectively monocrystallized. Thus, the obtained elongate bonded core assembly 40 finally consists of a ferrite single crystal.

The bonded and monocrystallized elongate core assembly 40 is then subjected to a process of filling the magnetic gap 42 with the molten glass 44. Successively, the elongate assembly 40 is cut across its length at predetermined intervals along the length, for producing plural ferrite cores 46 of the invention. Before each ferrite core 46 is completed, the pair of bonded portions adjacent to the magnetic gap 42 are cut off so that the gap 42 is exposed and the cut surface serves as the medium-contacting surface 48 for sliding contact with a magnetic recording medium. With the removal of the above pair of bonded portions, the core element blocks 30, 32 are bonded together solely at the other pair of bonded portions opposite to the cut-off portions. Thus, the ferrite core 46 is finally formed with a generally annular magnetic circuit.

While all of the illustrated embodiments use two core elements to constitute a magnetic head core of generally ring-shaped cross section (annular magnetic circuit), it will be appreciated to use three or more core elements. While a monocrystalline core element used in the illustrated embodiments has a ferrite single crystal portion located adjacent to a magnetic gap, it is possible that the monocrystalline portion be located at the opposite end portion remote from the magnetic gap. In this case, the ferrite single crystal is caused to grow in the ferrite polycrystal portions located on opposite sides of the magnetic gap, so that the opposed portions defining the gap consists of a ferrite single crystal.

As described hitherto, the instant method uses a combination of two or more elements of ferrite to constitute a ferrite core of the invention which has a generally annular or toroidal magnetic circuit. Since a magnetic gap is formed by opposed surfaces of the two separate core elements which are bonded together, the gap can be formed with a very small width, which is the distance between the two opposed core elements. Accordingly, the core of the invention is suitably applicable for magnetic heads for video tape recorders and computers, which require the head core to have a magnetic gap as small as 0.4 to 3 microns. According to the method of the invention, the core can be formed with such a small magnetic gap. Another important advantage of the invention resides in the manner of bonding the core elements through solid-solid reaction at the abutting portions of the elements. This solid-solid reaction bonding substantially eliminates otherwise possible presence of a gap at the abutting and bonding surfaces, i.e., a rear gap located remote from the magnetic gap at the front end of the core. The elimination of the rear gap results in a decrease in magnetic resistance of the core, which in turn contributes to improvement in the sensitivity and S/N ratio of the magnetic head.

Furthermore, the ferrite magnetic head core of the invention is monocrystalline at least at its portions in the vicinity of the magnetic gap and medium-contacting surfaces, thanks to the single crystal growth which has been discussed. Hence, the resistance to wear of the core caused by sliding contact of a magnetic recording medium is greatly increased. In addition, the use of ferrite polycrystal as one of the core elements makes a remarkable contribution to saving of the manufacturing cost, as compared with the conventional methods wherein ferrite single crystal is used to a relatively greater extent.

The invention is further illustrated by the following Example. It will be obvious that those examples are not construed to limit the scope of the invention.

Example 1

According to the method illustrated in Fig. 6, a coil-winding groove (34) was formed in an elongate block (30) of ferrite polycrystal which has an average grain size of about 10 µm, and a porosity of 0.1%, and shows a discontinuous grain growth. Prior to this groove forming process, the ferrite polycrystal block (30) was polished for smooth abutting surfaces. In the meantime, an elongate block (32) of ferrite single crystal, which had also been pre-polished for smooth abutting surfaces, was coated with a suitable chemically resistant film (38), except in an area corresponding to a gap-defining surface (36). The ferrite single crystal block (32) was then immersed for 90 minutes in a conc. solution of phosphoric acid at 50°C. As a result, the gap-defining surface (36) was etched by a depth of 2 μm (β).

Subsequently, the processed ferrite polycrystal block (30) with the coil-winding aperture (34), and the ferrite single crystal block (32) with the gap-defining surface (36) were butted together at their end portions remote from the gap-defining surface (36), after a 6N nitric acid solution had been applied to the abutting surfaces. Successively, the butted elongate blocks were dried and introduced into a furnace. Successively, the blocks (30, 32) were heated to 1150°C in a nitrogen gas, and further to 1350°C in a nitrogen gas containing 10% oxygen, at a rate of 300°C/hr, and further to 1400°C at a rate of 20°C/hr, whereby the ferrite single crystal block (32) was monocrystallized. Subsequently, the temperature was elevated to 1500°C at 300°C/hr, and left at that temperature for 10 hours. Then, the blocks (30, 32) were cooled.

The obtained elongate integral core assembly (40) was taken out from the furnace. The observation revealed that the ferrite polycrystal of the block (30) had been monocrystallized into a ferrite single crystal having the same crystal system (axes) as that of the ferrite single crystal of the monocrystalline block (32). A magnetic gap (42) formed in the core assembly (40) was filled with molten glass 44, and the assembly (40) was finally cut in parallel planes perpendicular to its length, which planes are evenly spaced from each other along the length of the assembly. Thus, plural magnetic head cores (46) were obtained. The front or top surfaces adjacent to the magnetic gap (42) were polished to a suitable convex curvature to provide a medium-contacting surface (48).

The measurement of the width of the magnetic gap (46) was 2 μm. A magnetic head using this core 50 was compared, in S/N ratio, with a magnetic head using a known core constituted by glass-bonded core elements. The magnetic head with the instant core (46) demonstrated 2dB improvement in the S/N ratio over the known head. It was found that the instant core (46) had a significantly reduced magnetic resistance at the abutting portions of the two ferrite blocks. A 500-hour running test was conducted to check for wear of the medium-contacting surface (48). The test revealed no uneven wear of the surface (48) and showed a good sliding fit of a magnetic tape on the surface (48). The characteristics of the magnetic head was never changed or deteriorated after the long hours of sliding contact of the tape with the medium-contacting surface (48).

Claims

1. A magnetic head core (20; 46) of generally ring shape having a coil-winding aperture (24; 34) for winding coils, and forming a generally annular magnetic circuit, wherein a magnetic gap (22; 42) of a predetermined width is formed transversely across the annulus of the magnetic circuit, characterized in that the magnetic circuit consists of a single crystal of ferrite.

2. A method of producing a magnetic head core (20; 46) made of ferrite and of generally ring shape so as to form a generally annular magnetic circuit and having a magnetic gap (22; 42) of a predetermined width formed transversely across the annulus of the magnetic circuit, including the steps of

forming said magnetic circuit by butting together plural core elements (16, 18; 30, 32) of ferrite into a generally ring-shaped assembly and bonding them together at mutually abutting surfaces (17) by means of solid-solid reaction so as to provide opposed portions of said magnetic circuit which define said magnetic gap at least one (16; 32) of said plural core elements consisting of or including a monocrystalline portion (15; 32) consisting of a ferrite single crystal,

monocrystallizing at least one of said opposed portions defining said magnetic gap as a result of growth of said ferrite single crystal into at least one originally polycrystalline portion of the core elements so that said two opposed portions and, in the completed head, surfaces which are slidably contacted by a magnetic medium are formed of a single crystal of ferrite.

3. A method according to claim 2 wherein when said plural core elements (16, 18; 30, 32) are bonded together, said monocrystalline portion (15; 32) constitutes one of said opposed portions and provides a gap-defining surface which cooperates with the other one of said opposed portions to define said magnetic gap.

4. A method according to claim 2, wherein said plural core elements consist of two core elements (16, 18; 30, 32) which have said opposed portions at one end respectively, and have said mutually abutting surfaces at their other end portions remote from said opposed portions, the two core elements being bonded together by means of solid-solid reaction at their said other end portions.

5. A method according to any one of claims 2 to 4 wherein after the monocrystallizing step, said opposed portions consist of a ferrite single crystal which provides opposed gap-defining surfaces defining said magnetic gap, said ferrite single crystal having a crystal face of (111) or (100).

6. A method according to any one of claims 2 to 5 wherein said magnetic gap has a width of 0.4—3 microns, which is the distance between said opposed end portions of two of said plural core elements.

7. A method according to claim 2 wherein said plural core elements consist of a first core element (18; 30) in the form of a polycrystalline block of ferrite polycrystal showing discontinuous grain growth and a second core element (16; 32) in the form of an at least partially monocrystalline block of ferrite including or consisting of said monocrystalline portion (15; 32) and wherein in said monocrystallizing step said monocrystalline portion grows towards at least one of the ferrite

polycrystal of said first core element (18; 30) and ferrite polycrytal (if any) present in said second core element (16; 32).

8. A method according to claim 7, wherein said mutually abutting surfaces (17) are disposed at the end portion of said assembly remote from said magnetic gap and the growth of the ferrite single crystal of said monocrystalline portion (15; 32) of said second core element (16; 32) proceeds across said mutually abutting surfaces (17) of said two core elements which have been bonded together by solid-solid reaction at said end portion of said assembly remote from the magnetic gap.

9. A method according to claim 7 or claim 8, wherein said assembly has a first pair of mutually abutting surfaces (17) on said opposed portions of said two core elements at one end portion of the assembly, and a second pair of mutually abutting surfaces (17) at the opposite end portion thereof, said first pair of mutually abutting surfaces being disposed outside said magnetic gap (22; 42) with respect to the magnetic circuit, and the growth of the ferrite single crystal of said monocrystalline portion (15; 32) of the second core element (16; 32) proceeds across said first and second pairs of mutually abutting surfaces of said two core elements which have been bonded together by solid-solid reaction at both said end portions of the assembly.

10. A method according to claim 9, wherein the ferrite single crystal of said monocrystalline portion of said second core element provides one of said medium-contacting surfaces.

11. A method according to any one of claims 7 to 10 wherein said first and second core elements are a pair of elongate blocks (30; 32) of ferrite which are butted and bonded together by means of solid-solid reaction into an elongate assembly having a cross-sectional shape corresponding to said generally annular magnetic circuit, said elongate assembly of the bonded two elongate blocks being cut in parallel planes perpendicular to the length direction of the elongate assembly, to obtain a plurality of said magnetic head cores.

12. A method according to any one of claims 7 to 11, wherein the ferrite single crystal (15; 32) of said monocrystalline portion of said second core element constitutes one of said opposed portions defining said magnetic gap, said ferrite single crystal having a crystal face of (111) or (100).

13. A method according to any one of claims 7 to 12 further comprising the step of maintaining said assembly of the two core elements at an elevated temperature for a predetermined time for smoothing the surface of said opposed portion or portions which has or have been monocrystallized from the ferrite polycrystal.

Patentansprüche

1. Magnetkopfkern (20; 46), der im allgemeinen ringförmig ist, mit einer Spulenwicklungsöffnung (24; 34) zum Wickeln von Spulen, und der einen im allgemeinen ringförmigen magnetischen Kreis bildet, wobei ein Magnetspalt (22; 42) gegebener Breite quer zu dem Ring des magnetischen Kreises ausgebildet ist, dadurch gekennzeichnet, daß der magnetische Kreis aus einem Ferrit-Einkristall besteht.

2. Verfahren zum Herstellen eines Magnetkopfkerns (20; 46) aus Ferrit, der im allgemeinen ringförmig ist, um einen im allgemeinen ringförmigen magnetischen Kreis zu bilden, und mit einem Magnetspalt (22; 42) gegebener Breite, der quer zu dem Ring des magnetischen Kreises ausgebildet ist, mit den Verfahrensschritten

der Bildung des magnetischen Kreises, indem mehrere Kerneinzelteile (16, 18; 30, 32) aus Ferrit zu einer im allgemeinen ringförmigen Gesamtheit zusammengefügt und an den gegenseitig anstoßenden Flächen (17) durch eine Festkörper-Festkörper-Reaktion verbunden werden, um gegenüberliegende Bereiche des magnetischen Kreises zu schaffen, welche den Magnetspalt begrenzen, wobei mindestens eines (16; 32) der mehreren Kerneinselteile aus einem monokristallinen Bereich (15; 32) aus einem Ferrit-Einkristall besteht oder einen solchen enthält,

der Monokristallisierung mindestens eines der gegenüberliegenden, den Magnetspalt begrenzenden Bereiche infolge eines Wachstums des Ferrit-Einkristalls in mindestens einen ursprünglich polykristallinen Bereich der Kerneinzelteile hinein, so daß die zwei gegenüberliegenden Bereiche und, in dem fertiggestellten Kopf, die vom einem magnetischen Medium gleitend kontaktierten Oberflächen aus einem Ferrit-Einkristall gebildet werden.

3. Verfahren nach Anspruch 2, bei dem, wenn die mehreren Kerneinzelteile (16, 18; 30, 32) miteinander verbunden sind, der monokristalline Bereich (15; 32) einen der gegenüberliegenden Bereiche bildet und eine Spaltbegrenzungsoberfläche liefert, die mit dem anderen der gegenüberliegenden Bereiche zur Begrenzung des Magnetspaltes zusammenwirkt.

4. Verfahren nach Anspruch 2, bei dem die mehreren Kerneinzelteile aus zwei Kerneinzelteilen (16, 18; 30, 32) bestehen, welche die gegenüberliegenden Bereiche jeweils an einem Ende aufweisen und die gegenseitig anstoßenden Flächen an ihren von den gegenüberliegenden Bereichen entfernten anderen Endabschnitten aufweisen, wobei die beiden Kerneinzelteile mittels einer Festkörper-Festkörper-Reaktion an diesen ihren anderen Endabschnitten miteinander verbunden sind.

5. Verfahren nach einem der Ansprüche 2 bis 4, bei dem nach dem Schritt der Monikristallisierung die gegenüberliegenden Bereiche aus einem Ferrit-Einkristall bestehen, welcher den Magnetspalt definierende, gegenüberliegende Spaltbegrenzungsoberflächen bildet, wobei der Ferrit-Einkristall eine (111) oder (100) Kristallfläche aufweist.

6. Verfahren nach einem der Ansprüche 2 bis 5, bei dem der Magnetspalt eine Breite von 0,4—3 Mikrometer hat, welches die Entfernung zwischen den gegenüberliegenden Endbereichen von zwei der mehreren Kerneinzelteile ist.

7. Verfahren nach Anspruch 2, bei dem die mehreren Kerneinzelteile aus einem ersten Kereinzelteil (18; 30) in Form eines polykristallinen Blockes eines Ferrit-Polykristalls, der ein diskontinuierliches Kornwachstum aufweist, und einem zweiten Kerneinzelteil (16; 32) in Form eines zumindest teilweise monokristallinen Blocks aus Ferrit, der den monokristallinen Bereich (15; 32) enthält oder aus diesem besteht, gebildet sind, und bei dem beim Schritt der Monokristallisierung der monokristalline Bereich zu mindestens einem aus dem Ferrit-Polykristall des ersten Kerneinzelteils (18; 30) und dem Ferrit-Polykristall (falls vorhanden) in dem zweiten Kerneinzelteil (16; 32) hinwächst.

8. Verfahren nach Anspruch 7, bei dem die gegenseitig anstoßenden Flächen (17) an dem von dem Magnetspalt entfernten Endbereich der Gesamtheit angeordnet sind und das Wachstum des Ferrit-Einkristalls des monokristallinen Bereichs (15; 32) des zweiten Kerneinzelteils (16; 32) über die gegenseitig anstoßenden Flächen (17) der beiden Kerneinzelteile fortschreitet, die durch eine Festkörper-Festkörper-Reaktion an dem von dem Magnetspalt entfernten Endbereich der Gesamtheit verbunden worden sind.

9. Verfahren nach Anspruch 7 oder 8, bei dem die Gesamtheit ein erstes Paar von gegenseitig anstoßenden Flächen (17) an den gegenüberliegenden Bereichen der beiden Kerneinzelteile an einem Endbereich der Gesamtheit aufweist, sowie ein zweites Paar von gegenseitig anstoßenden Flächen (17) an deren gegenüberliegendem Endbereich, wobei das erste Paar von gegenseitig anstoßenden Flächen bezüglich des magnetischen Kreises außerhalb des Magnetspaltes (22; 42) angeordnet ist und das Wachstum des Ferrit-Einkristalls des monokristallinen Bereichs (15; 32) des zweiten Kerneinzelteils (16; 32) über das erste und zweite Paar von gegenseitig anstoßenden Flächen der beiden Kerneinzelteile fortschreitet, die an den beiden Endbereichen der Gesamtheit durch eine Festkörper-Festkörper-Reaktion miteinander verbunden worden sind.

10. Verfahren nach Anspruch 9, bei dem der Ferrit-Einkristall des monokristallinen Bereichs des zweiten Kerneinzelteils eine der Kontaktoberflächen für das Medium bildet.

11. Verfahren nach einem der Ansprüche 7 bis 10, bei dem das erste und zweite Kerneinzelteil ein Paar von länglichen Blöcken (30; 32) aus Ferrit sind, die durch eine Festkörper-Festkörper-Reaktion zu einer länglichen Gesamtheit mit einem dem im allgemeinen ringförmigen magnetischen Kreis entsprechenden Querschnitt zusammengefügt und verbunden sind, wobei die längliche Gesamtheit der verbundenen beiden länglichen Blöcke in parallelen Ebenen senkrecht zur Längsrichtung der länglichen Gesamtheit zerschnitten wird, um eine Anzahl der Magnetkopfkerne zu erhalten.

12. Verfahren nach einem der Ansprüche 7 bis 11, bei dem der Ferrit-Einkristall (15; 32) des monokristallinen Abschnitts des zweiten Kerneinzelteils einen der den Magnetspalt begrenzenden gegenüberliegenden Bereiche bildet, wobei der Ferrit-Einkristall eine (111) oder (100) Kristallfläche aufweist.

13. Verfahren nach einem der Ansprüche 7 bis 12 mit dem weiteren Verfahrensschritt, die Gesamtheit der beiden Kerneinzelteile für eine vorgegebene Zeit auf einer erhöhten Temperatur zu halten, um die Oberfläche des oder der gegenüberliegenden Bereiche zu glätten, die ausgehend von dem Ferrit-Polykristall monokristallisiert worden sind.

Revendications

1. Noyau de tête magnétique (20; 46) d'une forme généralement annulaire ayant une ouverture d'enroulement de bobine (24; 34) pour enrouler des bobines, et formant un circuit magnétique de façon générale annulaire, dans lequel un intervalle magnétique (22; 42) d'une largeur prédéterminée est formé transversalement sur l'anneau du circuit magnétique, caractérisé en ce que le circuit magnétique est formé par un cristal unique de ferrite.

2. Procédé de fabrication d'un noyau de tête magnétique (20; 46) réalisé en ferrite et d'une forme généralement annulaire, pour former un circuit magnétique généralement annulaire et ayant un intervalle magnétique (22; 42) d'une largeur prédéterminée formé transversalement sur l'anneau du circuit magnétique, comprenant les étapes de

former ledit circuit magnétique par disposition bout à bout de plusieurs éléments de noyau (16, 18; 30, 32) de ferrite en un ensemble de forme générale d'un anneau et de les relier ensemble à des surfaces mutuellement en aboutement (17) au moyen d'une réaction solide-solide pour produire des portions opposées dudit circuit magnétique, qui définissant ledit intervalle magnétique à au moins l'un (16; 32) desdits plusieurs éléments de noyau consistant en ou comprenant une portion monocristalline (15; 32) formée par un cristal unique de ferrite,

de monocristallier au moins l'une desdites portions opposées définissant ledit intervalle magnétique comme résultat d'une croissance dudit cristal unique de ferrite, en au moins une portion initialement polycristalline des éléments de noyau si bien que lesdites deux portions magnétiques et, dans la tête finie, les surfaces qui sont en contact de glissement avec un milieu magnétique soient formées par un cristal unique de ferrite.

3. Procédé selon la revendication 2, selon laquelle, lorsque la pluralité d'éléments de noyau (16, 18; 30, 32) est reliée ensemble, ladite portion monocristalline (15; 32) constitue l'une des portions opposées et procure la surface de délimitation d'intervalle qui coopère avec l'autre portion opposée pour définir ledit intervalle magnétique.

4. Procédé selon la revendication 2, selon lequel la pluralité précitée d'éléments de noyau est formée par deux éléments de noyau (15, 18; 30, 32) qui ont des portions opposées à une extrémité respectivement, ayant les surfaces mutuellement

en aboutement à leurs autres portions d'extrémité, éloignées desdites portions opposées, lesdits deux éléments de noyau étant reliés ensemble au moyen d'une réaction solide-solide à leurs autres portions d'extrémité.

5. Procédé selon l'une des revendications 2 à 4, selon lequel, après l'opération de monocristallisation, lesdites portions opposées sont formées par un cristal unique de ferrite qui procure les surfaces opposées de délimitation de l'intervalle, qui définissent l'intervalle magnétique, ledit cristal unique de ferrite ayant une face de cristal de (111) ou (100).

6. Procédé selon l'une des revendications 2 à 5, caractérisé en ce que l'intervalle magnétique a une largeur de 0,4—3 microns, qui est la distance entre les portions d'extrémité opposées de deux parmi la pluralité d'éléments de noyau.

7. Procédé selon la revendication 2, selon lequel la pluralité d'éléments de noyau est formée par un premier élément de noyau (18; 30) en forme d'un bloc polycristallin d'un polycrystal de ferrite présentant une croissance de grains discontinue, et un second élément de noyau (16; 32) en forme d'un bloc au moins partiellement monocristallin de ferrite comprenant ou consistant en la portion monocristalline précitée (15; 32), et selon lequel pendant l'opération de monocristallisation, ladite portion monocristalline croît en direction d'au moins l'un parmi le polycristal de ferrite du premier élément de noyau (18; 30) et le polycristal de ferrite (s'il y en a) présent dans ledit second élément de noyau (16; 32).

8. Procédé selon la revendication 7, selon lequel les surfaces en aboutement mutuel (17) sont disposées à la portion d'extrémité de l'ensemble ou de l'assemblage précité, éloignée de l'intervalle magnétique, et la croissance du cristal unique de ferrite de ladite portion monocristalline (15; 32) dudit second élément de noyau précité (16; 32) s'effectue sur les surfaces mutuellement en aboutement (17) des deux éléments de noyau qui ont été reliés ensemble par une réaction solide-solide à leur portion d'extrémité de l'assemblage, qui est éloigné de l'intervalle magnétique.

9. Procédé selon la revendication 7 ou 8, selon lequel l'ensemble ou assemblage comporte une première paire de surfaces mutuellement en aboutement (17) aux portions opposées des deux éléments de noyau à une portion d'extrémité de l'ensemble et une seconde paire de surfaces en aboutement mutuelles (17) à la portion d'extrémité opposée, ladite première paire de surfaces mutuellement en aboutement étant disposée à l'extérieur de l'intervalle magnétique (22; 42) par rapport au circuit magnétique, et la croissance du cristal unique de ferrite de ladite portion monocristalline (15; 32) du second élément de noyau (16; 32) s'effectue sur lesdites première et seconde paires de surfaces mutuellement en aboutement des deux éléments de noyau qui ont été reliés ensemble par une réaction solide-solide auxdites deux portions d'extrémité de l'ensemble.

10. Procédé selon la revendication 9, selon lequel le cristal de ferrite unique de la portion monocristalline dudit second élément de noyau forme l'une desdites surfaces de contact de milieu.

11. Procédé selon l'une des revendications 7 à 10, selon lequel les premier et second éléments de noyau sont une paire de blocs allongés (30; 32) de ferrite, qui sont en aboutement et reliés ensemble au moyen d'une réaction solide-solide en un ensemble allongé ayant une forme de section transversale correspondant au circuit magnétique généralement annulaire, ledit ensemble allongé des deux blocs allongés reliés étant coupés dans des plans parallèles perpendiculaires à la direction de l'ensemble allongé, pour obtenir une pluralité de noyaux de têtes magnétiques précités.

12. Procédé selon l'une des revendications 7 à 11, dans lequel le cristal unique de ferrite (15; 32) de la portion monocristalline précitée du second élément de noyau précité constitue l'une des portions opposées qui défissent l'intervalle magnétique, ledit cristal de ferrite ayant une face de cristal de (111) ou (100).

13. Procédé selon l'une des revendications 7 à 12, comprenant en outre l'opération de maintenir l'assemblage ou l'ensemble des deux éléments de noyau à une température élevée pendant un temps prédéterminé pour lisser la surface de la ou des portion(s) opposée(s) qui sont ou ont été monocristallisées à partir d'un polycristal de ferrite.

FIG. 1

PRIOR ART

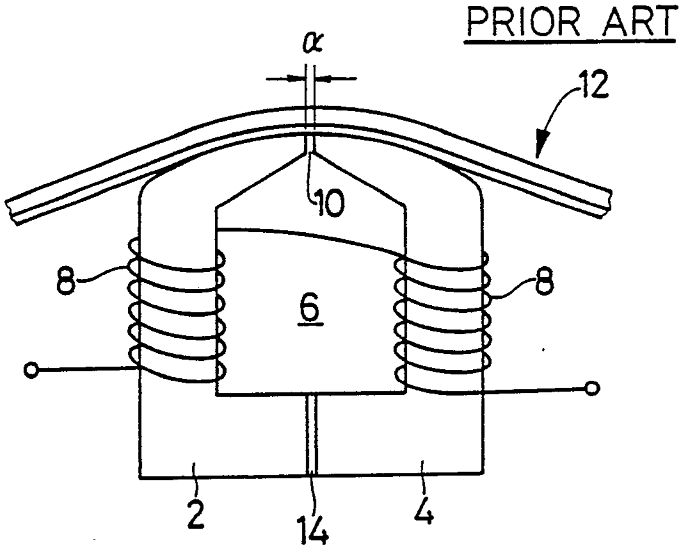

FIG. 2

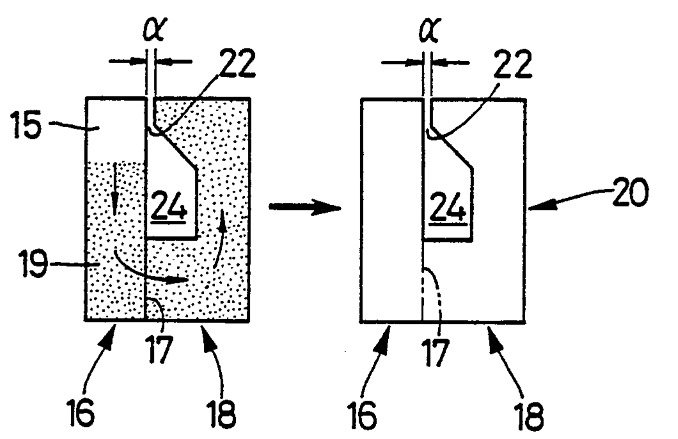

FIG. 3

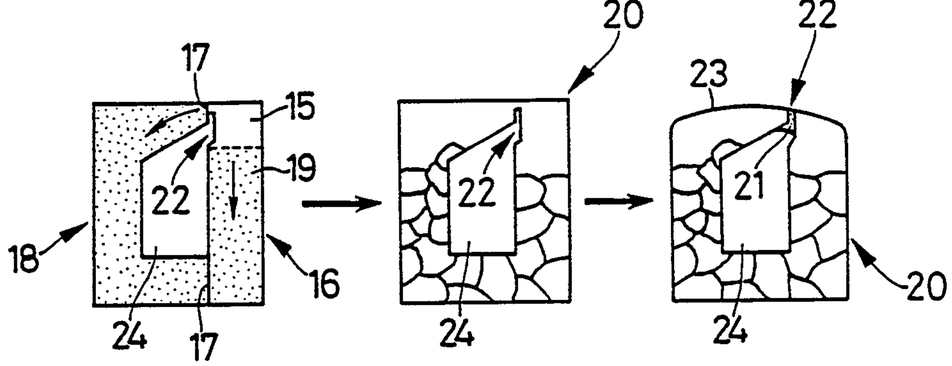

FIG. 4

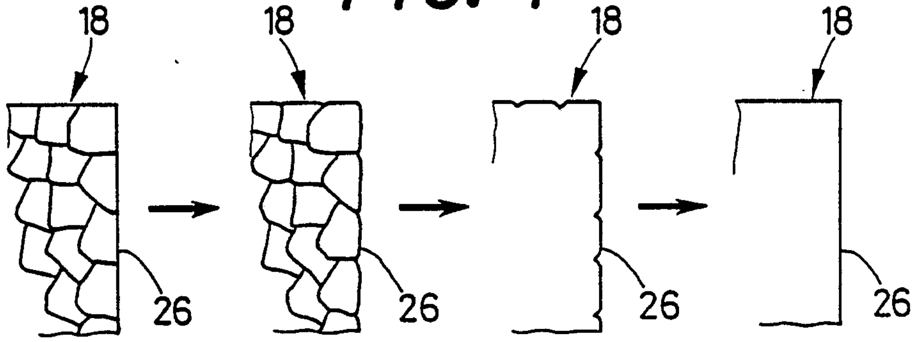

FIG. 5

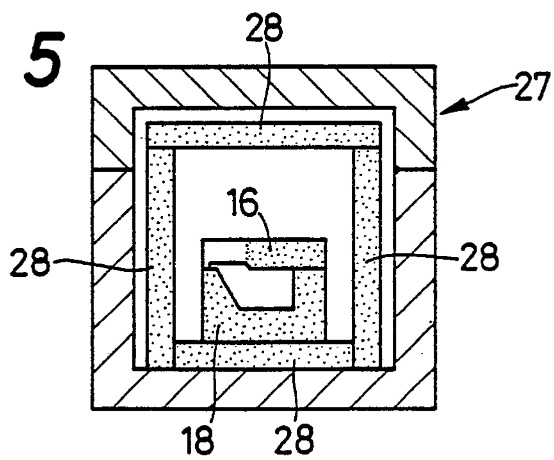

FIG. 6

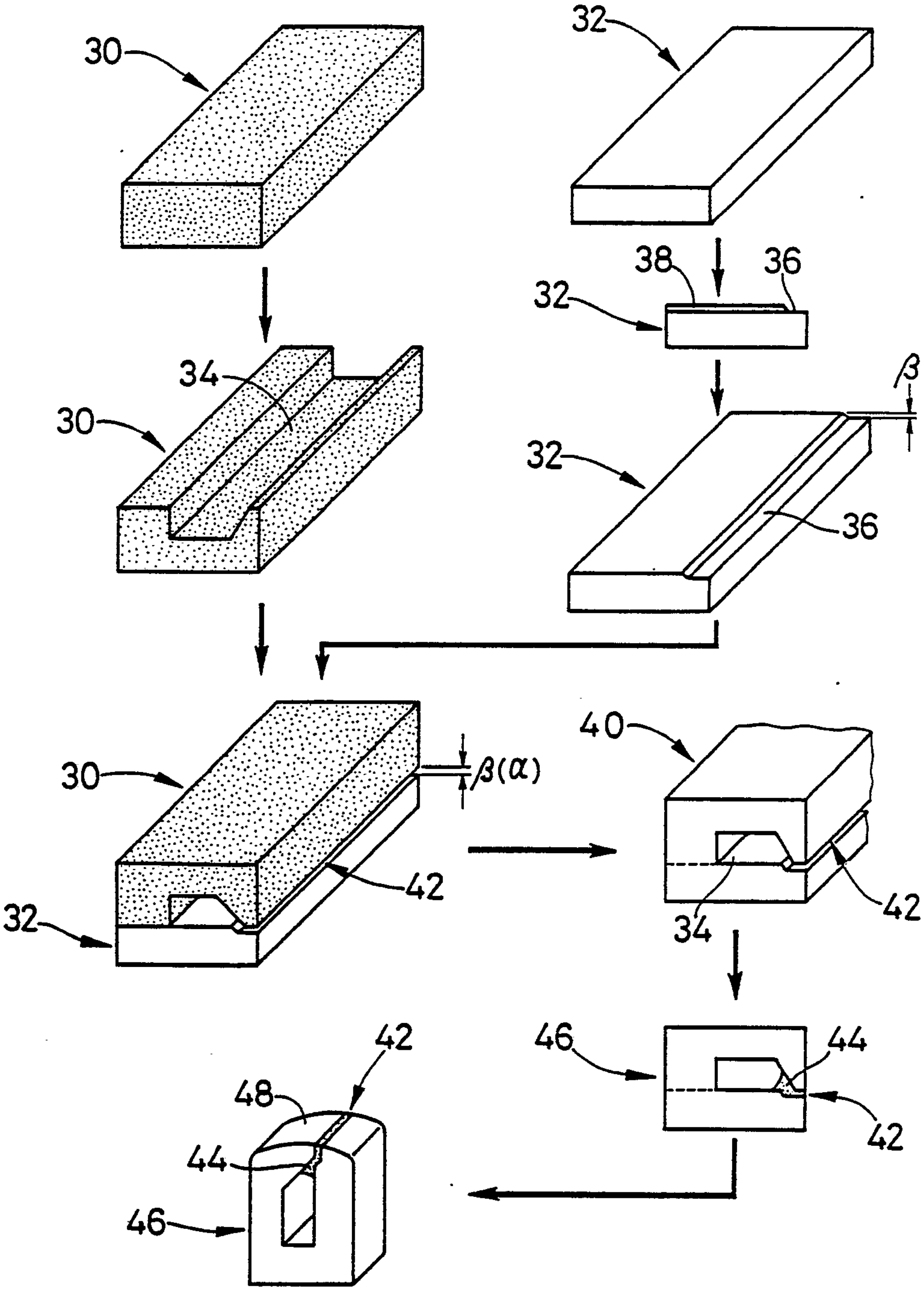

FIG. 7